

# Predator-Prey Interactions, Informational Complexity, and the Origins of Intelligence

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## ABSTRACT

The origins of intelligence, consciousness, awareness and higher brain functions have been a recent focus of attention by biologists and others. In evolutionary perspective they have described the changes in brain structure that have paralleled the growth of sophisticated functions. In addition some consideration has been given to the context(s) in which intelligence and higher functions would confer selective advantages to the possessors. It has been generally concluded that the initial function of intelligence was for the facilitation and exploitation of social relationships within a species. I here argue that intelligence probably arose, in the rainforest, as a means of exploiting complex information to competitive advantage. The rainforest is, and probably was, the most informationally complex habitat on earth. I further argue that rather than intraspecific activities it was interspecific exploitation that intelligence first facilitated. In particular I suggest that it was in the field of food finding and prey recognition that sophisticated learning and cognition evolved.

An outline examination of insect anti-predator adaptations is used to illustrate the possible steps that could have occurred in this process of progressive expansion of brain function. In addition other areas of interspecific interactions conducive to the evolution of intelligence are detailed and it is concluded that consciousness may have a major function as a process to prevent information saturation.

"the Germans . . . also developed a most ingenious paint for their U-boats to camouflage them against infra-red as well as against visible light. If a normal grey-painted ship, which is thus camouflaged well against typically grey sea, is viewed by infra-red it still looks grey but the sea looks blackish. They therefore had to make a paint which looked grey to the human eye, but blackish to the infra-red viewer. They achieved this . . ." Jones, 1979. 410-411.

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## Introduction

There have been a number of attempts in the last few years to provide a biological and evolutionary background for the evolution of intelligence in animals (for example Beck 1980, Humphrey 1976, Jolly 1966, Moynihan 1976, Robinson 1979, and Sagan 1977). A much

earlier treatment of complex learning in animals by Rensch (1950, 1967) is full of insights. In addition, the issues of concept formation, consciousness and animal awareness have been raised as legitimate concerns of biologists in general and behavior students in particular (the whole field was sparked into life by Griffin 1976, see also 1984, and Crook

1980). Although intelligence and the above-used related terms are difficult to define, general agreement exists on the range of phenomena that they comprise. In evolutionary terms one can ask what morphological, anatomical and behavioral characters accompanied the evolution of intelligence and related phenomena, this is the approach of Sagan (1977). This is an interesting question but a more fundamental problem concerns the situations in which intelligence-like properties were likely to have contributed to fitness (or to have acquired survival value; to use a less fashionable term). This approach has been adopted by Jolly (1966), Humphrey (1976), Robinson (1979), and Moynihan (1976). Of these Moynihan's (*ibid*) is the more comprehensive review that assumes that a plethora of factors was involved. Humphrey (*ibid*) assumes that intelligence arose to allow primates to cope with the complexities of social interactions.

In this paper I argue that mental processes akin to those subsumed under the term intelligence probably evolved when the ability to process complex information allowed some animals to exploit resources unavailable to other animals. Thus it is argued that the tropical rainforest was the cradle of intelligence since this, by virtue of the extreme range of species diversity and interspecific interactivity is the most information complex of all terrestrial habitats (Robinson 1977, reviews an extensive literature illustrating the interspecific complexity found in tropical rainforest and coral reef ecosystems). Furthermore it is argued that the context of interspecific behavior provided the most opportunity for exploiting the capacity to process complex information, particularly with respect to obtaining food.

This hypothesis implies a rejection of the contrary view that it is in the context of social interactions, within species behaviors, that the ability to process complex information first arose. The main arguments against the function of intelligence being primarily intraspecific (*i.e.* social) are that selection has favored the evolution of a circumscribed number of unambiguous social signals that facilitate information processing by recipients (displays

are displays because they are ritualised). The social context is thus a relatively simple one vis-a-vis information. Moynihan (1970) has emphasized that the total content of display repertoires is remarkably constant across wide taxonomic spectra, and over a range of degrees of sociality. On the other hand the continuing arms race between predators and prey has increased, and continues to do so, the complexity of signals generated by most potential prey other than those depending on aposematism.

I came to this view of the origins on intelligence as a consequence of a long-term interest in both sides of the predator-prey interaction (see Robinson 1969a, 1969b and particularly 1970). By reviewing the defensive adaptations of a range of tropical insects this paper provides evidence of the generation of information complexity. This complexification can lead, logically, to two major evolutionary pathways for predators. These are, quite simply, either the path of increasing specialization or the development of complex information processing capacities. In short it is argued that intelligence could have begun its evolution as a means of exploiting the considerable resources potentially available to a sophisticated tropical entomophage. Of course detecting the presence of organisms that have evolved complex anti-predator adaptations is only part of the information processing task involved in food-finding. Most organisms also have to "know" where and when to search. This may involve an extensive stored memory map and a scanning of clock and calendar information. And food-finding is not the only aspect of interspecific activity in which the tropical animal is potentially confronted by a vast array of information that can be used in a way that has great survival value. Many predators are also potential prey and need appropriate defensive behaviors. These defenses may utilize considerable quantities of information (for instance topographic details of home ranges for escape routes and refuges, specialized responses to specific predators and so on; see later). Animals may also need to store and process information about shelter from climatic variables and care of injuries and wounds.

At this stage it is appropriate to consider two ways in which information can be acquired from the environment. It can either be acquired 'phylogenetically', in the lifetime of the species; or in the lifetime of the individual. Lorenz's treatment of this issue (1965) is a really important one. There is little doubt that many animals are hard-wired to be highly successful in niches that require relatively small amounts of information processing. For instance an animal that feeds on only moving insects may (probably does) require a smaller program of food-finding information than one that can find motionless insects. On the other hand the more complex the environment the more there will be niches for animals that can utilize a wider range of information. Thus the tendency that seems to have occurred in the evolutionary process towards increase in brain size, and more individual non-genetic storage of information (see Jerison 1970). These matters are dealt with in the following treatment although not as extensively as they merit. Finally, in considering how animal information processing systems might operate I will review some possible functions of consciousness.

### Prey Detection Versus Defenses

Studies of the cues used in prey recognition, whether this is the principal focus or merely an incidental part, lag far behind other studies of the ethology of predation. For instance, only around 8% of Curio's (1976) review of predation behavior deals with prey recognition per se. This relative neglect is not due to the fact that the subject lacks intrinsic interest. For example, food-finding has been most heavily studied in birds. Many specialized entomophages are birds, yet we know little about how they recognize prey. Tinbergen (1963) has stressed our ignorance: "We know that young birds have, at the start, a very 'open mind' with regard to food; they respond to an enormous variety of objects, edible and inedible alike, and learn to confine themselves to those they find edible. My suggestion is that we have as yet no more than the faintest idea of the kinds of things such

birds learn when young'. There are some exceptions, see for instance, Greenberg (1984) but this is still true in essence. In the absence of direct studies it is tempting to make inferences about the behavior of predators from the presumed anti-predator adaptations of their prey. This kind of deduction is often both logical and useful. Thus anyone encountering the submarine painted in the manner described at the head of this paper would be able to deduce that the predator had, in this case, detectors capable of operating in visible light and the infra-red. Similarly if the so-called Stealth Bomber is ever built, an examination of its structure could lead to the deduction that radiodetection devices (Radar) exist. Examples of successful deduction of function from structure are readily found in the literature on recent military intelligence operations (see Jones, 1979, for intricate examples). (There are perils in deducing function from structure. Wood-Mason in 1878, published a description of a phasmid that he claimed was specialized for aquatic life. It had a flattened body, with a concave under-surface fringed with hair, and flattened limbs. All these adaptations are found in mayfly larvae that live in streams, where they are aquatic adaptations. However, in the case of *Prisopus berousus* they are adaptations to profile concealment when the insect is in its concealment posture, see Figure 16 in Robinson 1969a).

Despite these problems there are good examples of verified deductions of function from structure in relation to insect defensive systems. Thus color-matching camouflage, counter-shading, Batesian mimicry, and aposematism have all had their deduced functions subjected to experimental testing (rather than cite a plethora of references the reader is referred to Edmunds 1974, and Curio 1976, for examples and bibliographies). A particularly interesting example of such deduction concerns the function of eye-like markings in lepidoptera. These have long been regarded as startle devices, when large and closely similar to the vertebrate eye, and as deflection devices when small and generalised (Blest 1957). Blest (ibid) was able to show, experimentally, that the startle effect was greatest when the resemblance to an eye was closest.

A number of major visual defenses are still, to my knowledge, untested. These include outline concealing structures (Figure 1), obliterative patterning, flash coloration, and behaviors such as dash and freeze locomotion to name but a few. It is probable that obliterative patterning (= disruptive coloration) has been tested in its military applications. My own studies of the mimetic postures of stick- and leaf-mimicking insects (1969a, 1969b, 1970, 1973, 1981a) including data on more than fifty species of phasmids from Papua New Guinea that is as yet unpublished because of the impossibility of obtaining species identifications, have led me to conclusions about predator behavior. These can be summed up very simply; the insects have elaborate and complex devices that apparently serve to conceal structures that are typical of insects in particular and many arthropods in general. The structures concealed are segmentation, legs, heads, antennae and (often) wings. The concealment of these structures occurs in some phasmids that are not specialised stick and leaf-mimics and could have preceded the evolution of such mimicry although it now enhances the disguise. Functionally such concealment could have evolved in cryptic insects to enhance their crypticity and then been a preadaptation to plant part mimicry (= dis-

guise). This argument is presented in detail in Robinson (1969a, 1969b) and other examples are cited by Edmunds (1974). A revised outline of how stick and leaf-mimicry could have evolved is shown in Figures 2-6.

Merely looking at the visually operating systems of primary defence found in terrestrial arthropods allows us to make some guesses about how prey detection abilities could operate in predators. Thus the existence of color-matching camouflage, diurnal immobility, disruptive patterning and countershading suggests that visually hunting predators can recognize prey by their shape. A huge literature in experimental psychology suggests that animals can learn to respond to a considerable catalog of shapes or patterns. Humans also have an impressive ability to do this (Haber 1970), it is a right brain function. However a predator responding to the shape of a prey organism in the tropics would be confronted with an enormous array of specific learning tasks. It could encounter a multitude of species. (Recent studies of tropical forest insects in the canopy, by Erwin (1982, 1983), have suggested that estimates of the total number of insect species in the world needs upgrading from 1.5 million to as much as 30 million; most of these are in the tropics). Furthermore the hunting pressure of predators may have

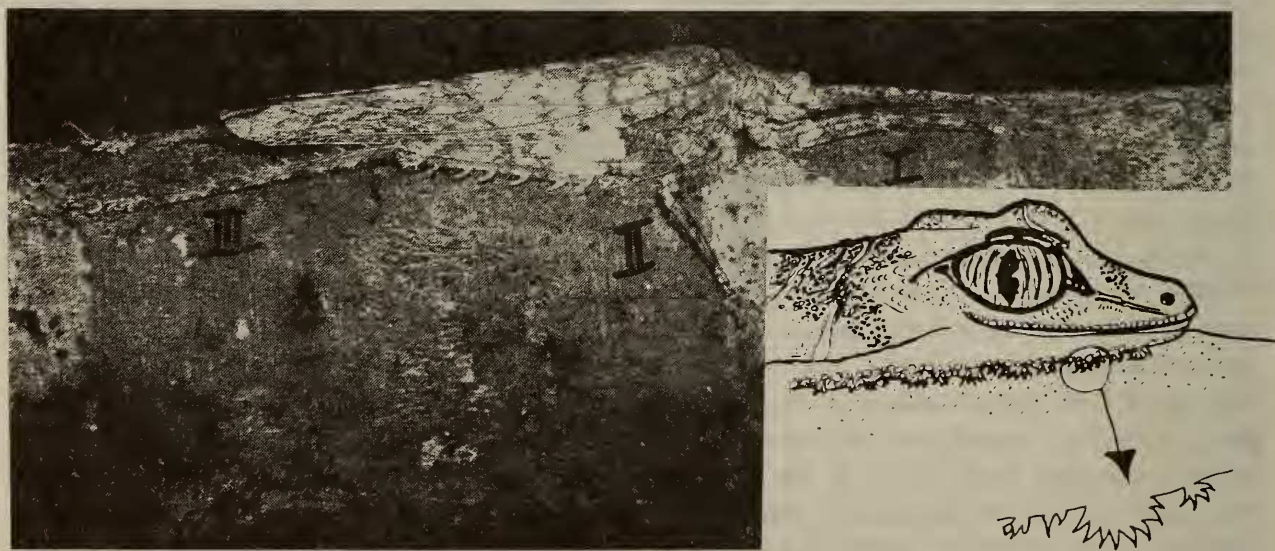


Fig. 1. Profile of the neotropical tettigoniid *Acanthodis curvidens* (Stål). This has both concealing coloration and a posture and structure that tend to conceal its outline. The inset shows the head of the leaf-tailed gecko *Uroplates fimbriata* which also rests on trees and has profile concealing devices such as the irregular-edged lateral fringe on the ventral surface. This, shown enlarged, breaks up the dividing line between the lizard and its substrate. (photo M. H. Robinson)

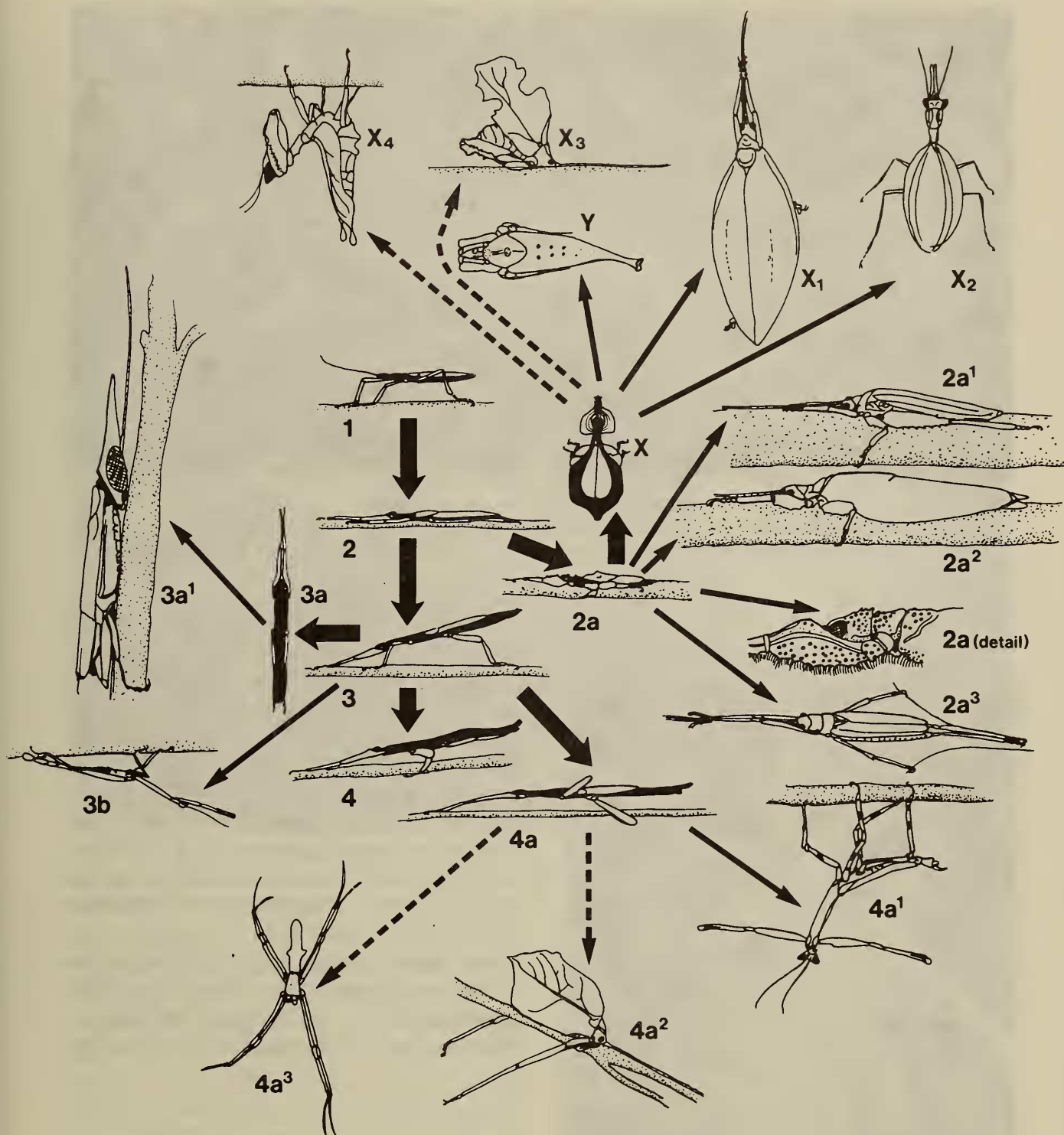


Fig. 2. The evolution of stick- and leaf-mimicry in the insect Order Phasmida and convergent postures found in other arthropods. The central grouping of insects with solid black bodies connected by broad arrows is the phasmid element of the diagram. The other figures show anatomically and/or posturally convergent forms. Explanation in Appendix 1.

tended to accentuate differences between appearances, by apostatic selection (Clark 1969), thereby increasing the learning task confronting predators, by producing aspect diversity (Rand 1967, Ricklefs and O'Rourke 1975).

Species diversity and aspect diversity combine to produce massive informational complexity. To treat this kind of complexity there are at least two conceivable mechanisms. One is to store information about all the prey that

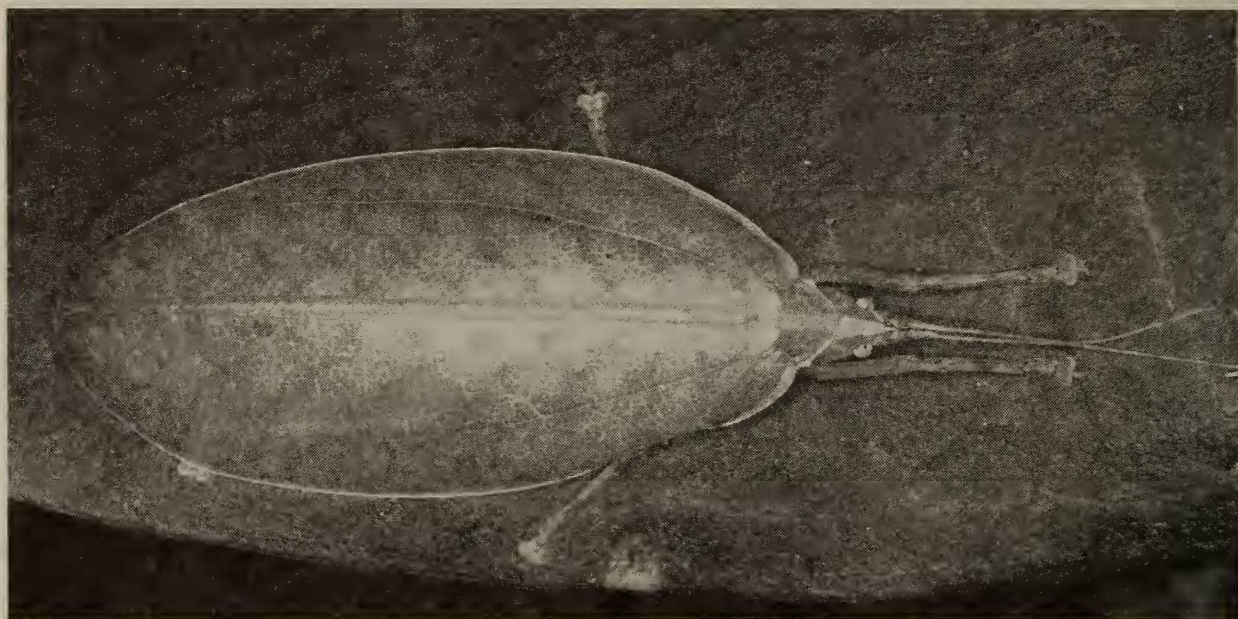


Fig. 3. The tettigoniid *Acauloplacella immunis* Brunner, from New Guinea, in its cryptic posture. The wings are flattened so that they tent over most of the intermediate and posterior legs and touch the leaf surface, producing a very low profile. Note the position of the anterior legs (compare with  $X_1$  on Figure 2). (Photo M. H. Robinson)



Fig. 4. The Australian preying mantis *Neomantis australis* (Saussure and Zehntner) which has a permanently flattened posture for the wings, this is essentially similar to that shown in Figure 3. (compare with  $X_2$  on Figure 2). (Photo M. H. Robinson)

are encountered and have an efficient system of reviewing the stored information (see later, for comments on this possibility). The other is to group the information into subsets and act on these; this is the process of stimulus generalization or nonverbal concept formation. I am inclined to think that predators may have an impossible task if they rely on individual recognition of prey types. Scanning the floppy-disc of memory could be an impossibly complex operation when the data base is massive. It would help to be able to recognize some general characteristic of subsets of the general assemblage of prey. To do this would require the beginnings of intelligence. What are some of the possible bases for subsets?

### Possible Simplifying Mechanisms

One, of course, is the recognition of the insect "taxonomically" by its diagnostic parts. This is suggested by the extreme modifications for concealing these parts which are discussed above, and illustrated in Figures 2–6. There is, so far, little evidence that this is how prey recognition works. However, I have carried out some experiments the results of



Fig. 5. Leaf insect from New Guinea, note the huge gauntlet-like dilated and flattened femora (arrowed) of all six legs. The arrows show the direction in which the legs move to form the resting outline shown in X of Figure 2. (Photo M. H. Robinson)

which are at least suggestive (Robinson 1970). These show that some predators can use the presence of heads or legs to find otherwise concealed prey. There are also experiments that show that even creatures with such small brains as jumping spiders (*salticidae*) respond to leg-like projections on models when attacking prey (Drees 1952). And a number of birds show head-recognition in the manipulation of prey. A further possibility is that predators may respond to the bilateral symmetry of insect prey. Cryptic patterns on the wings of moths are invariably bilaterally symmetrical. The use of symmetry as a detection device can be easily demonstrated in human subjects confronted with photographs of cryptic insects. It would provide an almost uni-

versal cue in the detection of immobile cryptic prey since the developmental processes of insects seem to rigidly produce symmetry of patterning. Significantly, military camouflage patterns avoid this symmetry in moth-like objects as shown in Figure 7. Elegant experiments by Delius and Nowak (1982) have shown that pigeons can learn to recognize symmetry and make discriminations between patterns, that are based on symmetry. It has also been shown that pigeons can solve inversion problems at least as well as humans (Hollard and Delius 1982).

Thus it is possible that predators may have an 'averbal taxonomic ability' (named after Koehler's 'averbal counting ability' concept, see Rensch 1950) and also an 'averbal sym-

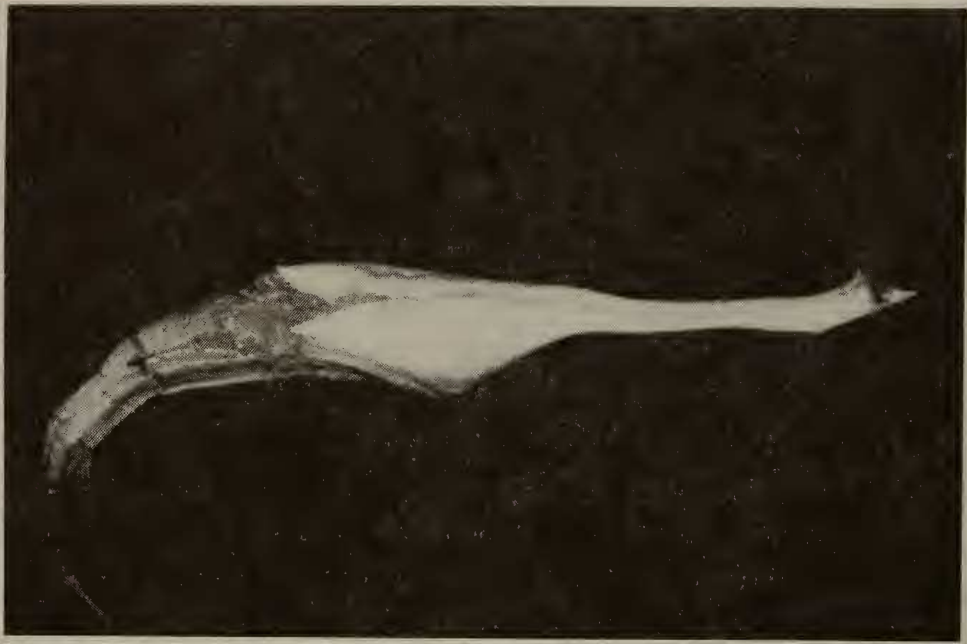


Fig. 6. The orb-web spider *Arachnura melanura*. This sits at the center of its web with all its legs folded against themselves or the margins of the body. Legs I and II project forwards, legs III and IV fold against the body. The spider is bright yellow and flower-like. (Photo M. H. Robinson)

metry discrimination'. These abilities, it can be argued, could imply complex mental phenomena. If it turns out that visually hunting predators can store and review large numbers of bits of information, in a 'directory of prey shapes', which is not impossible, then they will prove to have an information processing system that could be an important adjunct/precursor of induction.

It has been suggested, for two reasons, that orangutans may be intelligent (Galdikas 1978). One reason is that although they are the least social of the great apes they have to store social information for long periods between encounters. I do not find this very convincing. On the other hand the fact that they may have a sense of 'avermal botanic taxonomy' to cope with a plethora of plants is suggestive. (For comments on orangutan intelligence see also Maple 1980).

#### Other Complex Information Processing Tasks

Food finding is not the only situation that could evoke the evolution of intelligence. I suggested earlier that there were a number of

interspecific tasks that faced many animals and were of great survival importance. In many of these cases the ability to store, review and "abstract" complex information could be crucial to success. Admittedly animals can be well adapted in tropical forest niches without apparently using this information, but its existence opens up the possibility that a clever animal would have a greater evolutionary potential. In these cases, reviewed below, conventional learning paradigms may be inapplicable—animals may need new types of plastic behavior to exploit the new opportunities to the full. A case in point involves the acquisition of detailed familiarity with a home range (familiarity with a territory may be a similar phenomenon, worth consideration at length, but omitted here for space considerations). Many mammals show detailed familiarity with the topography and contents of their home range. This knowledge can be of value to them in locating food and in the urgent situation of finding escape routes and refuges when pursued, or confronted, by a predator. It is not clear that the kind of learning involved in this kind of information acquisition fits any conventional paradigms. The learning of maze layouts by rats, which were merely given maze experience without extraneous re-

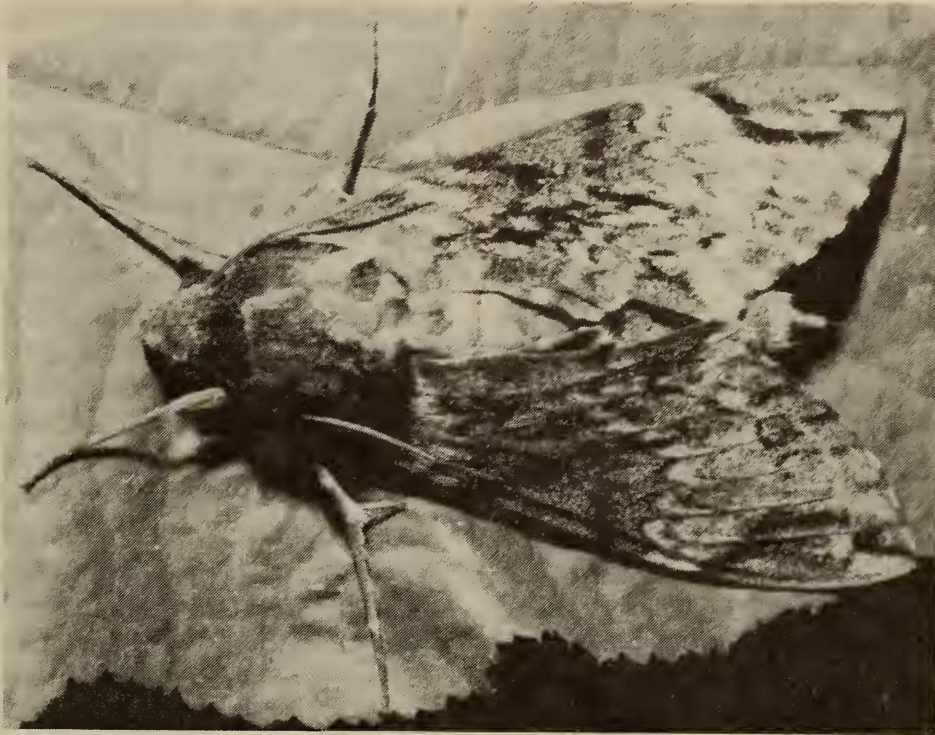


Fig. 7. Photograph of a sphinx moth showing symmetrical markings and a delta-winged bomber showing asymmetrical camouflage markings (moth photo M. H. Robinson, aircraft courtesy of National Air and Space Museum, Smithsonian Institution).

inforcement, was called 'latent learning' by Hinde (1966). He has since pointed out some of the problems involved in this kind of categorization but argues that 'place learning' could best be explained in cognitive rather than stimulus-response terms (Hinde 1970). Mackintosh (1983) remarks of these phenomena "the topic of maze learning has shown a

marked revival in recent years, partly due to the suggestion that such learning depends on the establishment of a cognitive map of the rat's environment'. Bernard (1983) still uses the term latent learning, cites a 1930 experiment as an example, but states that "a detailed geographical knowledge of the home area could be crucial in escaping from pred-

ators''. It seems to me that this kind of conventionally unrewarded learning is of great interest. There is a dearth of field studies on the extent to which free-living animals use a cognitive map. Many observations suggest that they do. It is tempting to speculate, by introspection, that some kind of mental reward may accompany such types of learning. The possibility that some kinds of locality learning may be of survival value only in the context of extremely rare events is raised by the use of water holes by baboons in East Africa. This rare use may occur during droughts that may be many, many years apart. Here the old members of a troop prove their usefulness as repositories of knowledge (Altmann and Altmann 1970). The occurrence of rare climatic events even in purportedly stable, humid tropics (Rand and Rand 1982), suggests that animals could gain survival advantages from long term knowledge of resource distribution.

Lorenz (1981) has argued that exploratory behavior plays an important part in the kinds of mental cartography described above, and some classic treatments suggest that curiosity is an important appetitive behavior. The linkage or parallel of exploration to play is also a link to intelligence.

Tool use by animals (Beck 1980, Griffin 1984) may be another instance where intelligence may immediately confer an adaptive advantage. Insight learning may give an opportunity to exploit resources that are out of reach or otherwise unavailable. The classic experiments of Kohler (1925) are still cited as examples, although Goodall's chimpanzee's termite catching behavior (1968) may have arisen this way.

Animals also have to cope with climatic variables that affect the distribution of food supplies. Species that range widely to exploit resources that are localized in space and time could benefit from having a capacity for learning phenological sequences of flowering, fruiting and leafing (for instance). Using a calendar of biological seasonality would be as useful as possessing a cognitive map of resource distribution. Knowledge thus acquired could guide an animal to flowers, fruits and new leaves or to the animals (insects per-

haps) that feed on them. Of course simple trial and error patrolling would achieve the same end, but could involve the expenditure of a great deal more energy. A calendar would be more efficient.

Most animals face the possibility, in their lives, of experiencing injuries or wounds. Predators, in particular, because of their extreme reliance on maximum efficiency in capturing prey, cannot afford debilitating injuries. They must therefore not only learn what organisms are edible but also what organisms they should not attack. The avoidance learning of distasteful and dangerous organisms may be simplified by the evolution of warning coloration by prey organisms. On the other hand the existence of Batesian mimicry and other kinds of false warning coloration means that a "simplistic" response to aposematism could result in a predator ignoring a whole range of potentially edible organisms. Although there has been extensive research showing that predators learn to generalize aversive responses to aposematic prey, there have been few studies of whether sophisticated predators can learn to detect deception. I suspect that such discrimination will eventually be discovered. My own studies suggest that tamarins (small monkeys) are not fooled by eye-markings and startle displays, although birds are (Robinson 1966, Blest 1957). Furthermore there is a whole range of insects that bring stings and other weapons into play only as secondary defense and the alpha predator needs to be able to discriminate between these and harmless look-alikes. It is in the tropics that by far the greatest number of kinds of potential prey could either be dangerous or be falsifying information (lying) about their dangerousness. Thus the need for intelligent behavior in detecting food is likely to be paralleled by a similar need in determining sources of danger. One of the most intriguing aspects of animal behavior is the care of injuries and wounds. This care is of immediate adaptive value. As far as I know it has not been studied by ethologists; it should be possible to do so without inflicting pain and injury on experimental animals.

This brief review suggests that the begin-

nings of tendencies to process complex information, through systems of complex learning and cognition, could provide a whole series of adaptive windows for the possessor in fields other than food-finding. This raises the question of the evolution of consciousness, does this have some relationship to information processing?

### Consciousness

Mayr (1982) has argued that consciousness is undefinable and, by implication, not susceptible to discussion or study: "As far as consciousness is concerned, it is impossible to define it . . . therefore detailed discussion is impossible." Griffin (1984) ranges over a whole series of attributes of consciousness without approaching a single satisfactory definition. Crook (1980) also uses a multi-component definition.

To avoid definitional problems it is perhaps appropriate to consider particular aspects of consciousness. Thus there is the question of memory-awareness as it might be called. One introspectively available datum is that only a small portion of the memory store is available to our minds at any one time. It is as if a huge memory store (nonconscious) were scanned and the appropriate piece of information were brought onto the screen of the mind for conscious viewing. The impossibility of being simultaneously aware of the entire contents of a memory store suggests one major function of consciousness. It allows for ordered review of the information that is necessary for action. It is difficult to imagine any other mechanism that could allow selective review of stored information in animals. To the computer enthusiast, reading off the sequential content of a ROM provides a bewildering succession of information. The brain does not consciously work that way. Information is not presented in massive successional series. The extensive content of the nonconscious visual memory banks is nicely illustrated by the act of reviewing a box of color slides from, say, twenty years ago. De-

spite the enormous volume of visual experiences that have occupied the twenty intervening years most people will recall all the scenes on a roll of film and be able to add verbal detail to describe them (I owe this illustration to Blakeslee 1980). This is, coldly considered, an amazing feat. Lorenz (1981) has drawn attention to a similar phenomenon: "It borders on the miraculous the way in which gestalt perception can abstract configurations of distinctive features from a chaotic background of accidental stimulus data, and then retain these over the years." It is interesting that for most people sights are retained in greater profusion than sounds and smells. We may be impinging on a device that once served our predatory past. Perhaps consciousness is not the problem; perhaps nonconsciousness is really the important adaptation. Without it all animals could be in a state of constant information shock, overwhelmed by the simultaneous input of countless bits of stored data.

### Conclusion

If intelligence is a response to information-processing in an information-rich environment this may have been only its originating function. Because the adaptive steps to higher learning conferred advantages in enabling the possessor to exploit new resources, there is no need to assume that this was the only function. In postulating the origins of intelligence we have merely described an interspecific climate that favored the start of an evolutionary progression. The milieu of increasing social complexity may then have added its synergism to that of interspecific complexity. Humphrey (1975) and Jolly (1966) have, perhaps, identified a later stage of the evolutionary progression.

I have suggested elsewhere (Robinson 1977, 1981b) that there is a fundamental difference between tropical biology in complex habitats (rainforests and coral reefs) and the biology of all other regions. I have characterized this difference as being reflected in the utter complexity of the biotic component of the habitat.

The suggestion made throughout this paper is that one way of coping with biotic complexity is for some animals to have a capacity for plastic behavior and for individuals to store, process and adaptively reorganize information during their lifetimes. (In contradistinction to the phylogenetic processing of information involved in preprogrammed behaviors.) When animals that evolved in information-rich environments later moved into relatively simple ones, those that had evolved sophisticated cognition and intelligence may have had a surplus capacity. This release from pressures of survival may have been analogous in many ways to infancy in higher mammals. It could have been a period in which mental exploration and intellectual play were possible for the first time. It could have been the point at which abstract thought had its first flowering. It may have happened when our ancestors moved from the information-rich forests into the savannas.

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## Appendix I

### The Evolution of Stick- and Leaf-mimicry in the Phasmids and Convergent Postures in Other Arthropods

The argument is simply that, from a relatively generalized ancestor (1), adaptations for profile concealment in cryptic postures led to apparent elongation. These adaptations included extension of legs I in front of the head (which incidentally concealed its structure and the antennae) and posterior extension of legs II and III apposed to the body as shown in 2. This concealed the legs and profile. Together these behaviors enhanced the stick-like appearance of the resting insect. A further step would be to become increasingly flattened (as

in element 2a and detail: this is the insect *Prisopus berosus*, referred to in the text, that was once assumed to be aquatic). Dorso-ventral flattening could be a pre-adaptation to leaf-mimicry as in X. Once the insect became elongate and had appropriate leg postures the next evolutionary step could be the one to stand-alone stick mimicry shown in element 3. Once this is achieved the insect is no longer cryptic but a true mimic and can be protected from predators by its resemblance to the inedible rather than merging with a background. Disguise is substituted for concealment. Element 3a is the total stick position assumed by many phasmids after dropping from a substrate—all legs are folded against the body. Stages 4 and 4a are a further enhancement of stick posture 3. They involve either structural concealment or structural and postural concealments of other legs in a stick-with-branches position. The insect shown in element 4a is illustrated in detail by Robinson 1969a.

Around the central block of phasmids the other drawings show similar postures and structures found in other arthropod groups, 2a<sup>1</sup> and 2a<sup>2</sup> are tettigoniid resting postures that exactly parallel that shown in 2a. Element 2a<sup>1</sup> is the tettigoniid shown in Figure 1 while element 2a<sup>2</sup> is a tettigoniid from Asia (see Robinson 1977 for details). Element 2a<sup>3</sup> is another tettigoniid that assumes an essentially similar posture to 2a but which rests on flat rather than curved surfaces (from Robinson 1969b). Elements 4a<sup>1</sup>, 4a<sup>2</sup> and 4a<sup>3</sup> show leg concealment postures in which legs become branches associated with a stick or leaf. Element 4a<sup>1</sup> is a West African mantid that assumes a stick-with-branches position (from Robinson 1966), 4a<sup>2</sup> is a dead leaf katydid (from Robinson 1969a) and 4a<sup>3</sup> is the spider *Dinopis rufipes* which hangs from vegetation with its legs grouped into four stick-like units (original, from a color slide). Element 3b is a stick posture found in stick-like mantids which involves the protraction of both legs I in a similar manner to that shown in 3. Element 3a<sup>1</sup> shows the grass dwelling mantid *Pyrgomantis pallida* in its resting posture which is essentially similar to 2 and 3a but with the

anterior legs folded beneath the thorax and very closely apposed to it (original from a color slide).

Elements  $X_1$ ,  $X_2$  two insects, a tettigoniid and mantid respectively, that are at a stage that could lead to the evolution of leaf mimicry. Both have broadly flattened wings that are leaf-like and cover the body and parts of

the legs. Compare with Figures 3 and 4. Elements  $X_3$  and  $X_4$  are functionally leaf mimicks, with complex leg concealment postures (see Robinson 1969a for details). Element Y is the orb-weaving spider *Arachnura melanura* that is a flower mimic with a complex mimetic posture involving leg concealment and specialized form (compare with Figure 6).

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## Enhancement of Mitogen Responsiveness in Mice Exposed to Low Concentrations of Cadmium in Drinking Water

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### ABSTRACT

The effects of cadmium on the immune system have been extensively studied with reports of both immunoenhancement and immunosuppression associated with cadmium exposure. These studies have generally used a cadmium dose well above normal levels of exposure. In the present study, we report the immunologic effects of exposure to very low levels of cadmium using the lymphocyte transformation test as a reflection of immunocompetence. Male Balb/c mice were exposed to cadmium, 0, 0.01, 0.1, 1.0 and 10 ppm, in drinking water for 4-5 weeks at which time the mitogen- and MLC-responsiveness of their splenic mononuclear cells was determined in a standard lymphocyte transformation test. Cadmium exposure was associated with an enhanced response to both LPS and Con A. The LPS response of mice exposed to 10 ppm cadmium was statistically significantly higher than that of non-cadmium exposed mice. Cadmium exposure had no effect on either unstimulated DNA synthesis or that induced by co-culture with allogeneic or syngeneic, irradiated splenocytes. These results suggest that the immune system may be modified by very low levels of cadmium in the environment.